

The Importance of AGN in an Assembling Galaxy Cluster

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Abstract.

We present results from our multi-wavelength study of SG1120, a super galaxy group at $z = 0.37$ that will merge to form a galaxy cluster comparable in mass to Coma. We have spectroscopically confirmed 174 members in the four X-ray luminous groups that make up SG1120, and these groups have velocity dispersions of $\sigma_{1D} = 303 - 580 \text{ km s}^{-1}$. We find that the supergroup has an excess of $24\mu\text{m}$ members relative to CL 1358+62, a rich galaxy cluster at $z = 0.33$. SG1120 also has an increasing fraction of $24\mu\text{m}$ members with decreasing local galaxy density, *i.e.* an infrared-density relation, that is not observed in the rich cluster. We detect nine of the group galaxies in VLA 1.4 Ghz imaging, and comparison of the radio to total infrared luminosities indicates that $\sim 30\%$ of these radio-detected members have AGN. The radio map also reveals that one of the brightest group galaxies has radio jets. We are currently analysing the 1.4 Ghz observations to determine if AGN can significantly heat the intrahalo medium and if AGN are related to the excess of $24\mu\text{m}$ members.

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INTRODUCTION

Galaxy groups may be the key to understanding the interplay between galaxy evolution and environment because: 1) most galaxies in the local universe are in groups [*e.g.* 1]; and 2) hierarchical structure formation predicts that galaxy clusters assemble from the merger and accretion of smaller structures such as groups [2]. Observational studies also have found that the quenching of star formation needed to transform an active galaxy into a passive system occurs outside the cluster cores ($R_p > 2 \text{ Mpc}$) [3], *i.e.* in lower density (group-like) environments.

Although less massive than galaxy clusters, galaxy groups in the local universe do have more in common with clusters than with the field population, *e.g.* higher early-type fractions and lower mean star formation rates than the field [4, 5, 6]. However, whether star formation in intermediate redshift groups is initially enhanced or simply quenched relative to the field is debated. Another closely linked question is whether active galactic nuclei (in radio/mechanical mode) have a short but critical role in quenching the star formation [7, 8], *e.g.* simulations by Bhattacharya et al. [9] show that AGN feedback does decrease the gas density and star formation in galaxies in the group core. AGN can also heat the intra-halo medium and thus help explain the high entropy floors observed in galaxy groups and clusters [10]. Note that several studies find that the AGN fraction in local clusters increases with decreasing velocity dispersion (mass) [11, 12], *i.e.* the

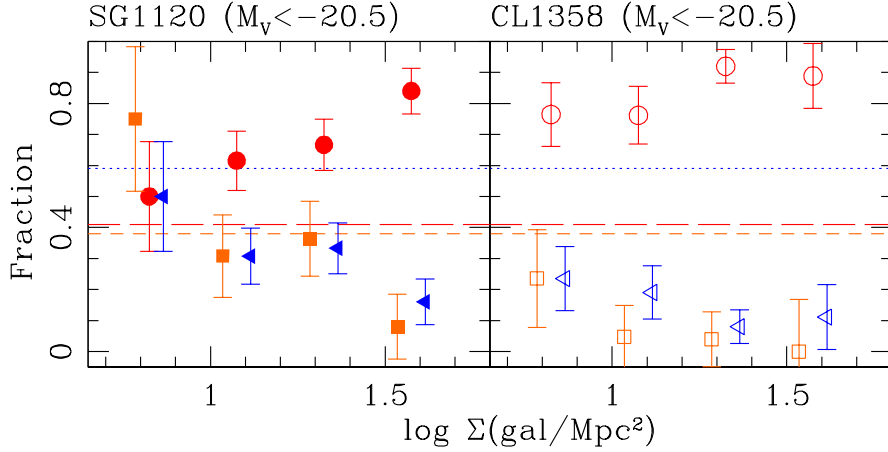


FIGURE 1. Relative fraction of absorption-line (circles), emission-line (triangles), and $24\mu\text{m}$ (squares) members as a function of local galaxy surface density in the groups (SG1120, left panel, filled symbols) and cluster (CL1358, right panel, open symbols); the points are offset slightly in $\log \Sigma$ for clarity. Both panels show the luminosity-selected ($M_V < -20.5$) samples. We show the fraction of absorption-line (long-dash), emission-line (dotted), and $24\mu\text{m}$ (short-dash) galaxies in the field as horizontal lines in both panels. Only in the supergroup does the $24\mu\text{m}$ fraction measurably increase with decreasing local density, *i.e.* an infrared star formation–density relation. At the lowest galaxy densities in the supergroup, the $24\mu\text{m}$ fraction is even higher than in the field.

AGN fraction should be higher in group-massed halos ($M \sim 10^{14} M_\odot$).

The question then is whether the evolution of galaxies in clusters is driven primarily on group or on cluster scales. Our discovery of a supergroup of galaxies at $z = 0.37$ allows us to uniquely answer this question. The supergroup (hereafter SG1120) is composed of multiple galaxy groups that we have shown will merge into a cluster comparable in mass to Coma by $z \sim 0$ [13]. First results from our multi-wavelength study show that the group galaxies are in transition: SG1120 has a high fraction of early-type members [14], yet several of the most massive group galaxies are growing by dissipationless merging at $z < 0.4$ [15]. Here we test whether the group galaxies have enhanced activity relative to the field by combining MIPS $24\mu\text{m}$ and VLA 1.4 GHz imaging to measure total star formation rates and identify AGN.

RESULTS

Our multi-wavelength study of SG1120 ($z = 0.37$) is unique among existing surveys at intermediate redshift because we: 1) have a large number (174) of spectroscopically confirmed group galaxies; 2) compare to the massive, dynamically relaxed cluster CL1358+62 ($z = 0.33$, 232 members) [16]; and 3) also compare to a sample of field galaxies (87 galaxies at $0.25 \leq z \leq 0.45$) that have been observed and analyzed in the same manner as the group and cluster galaxies [17]. Our $24\mu\text{m}$ imaging identifies all galaxies with obscured star formation rates of $3M_\odot \text{ yr}^{-1}$ or greater, regardless of galaxy mass.

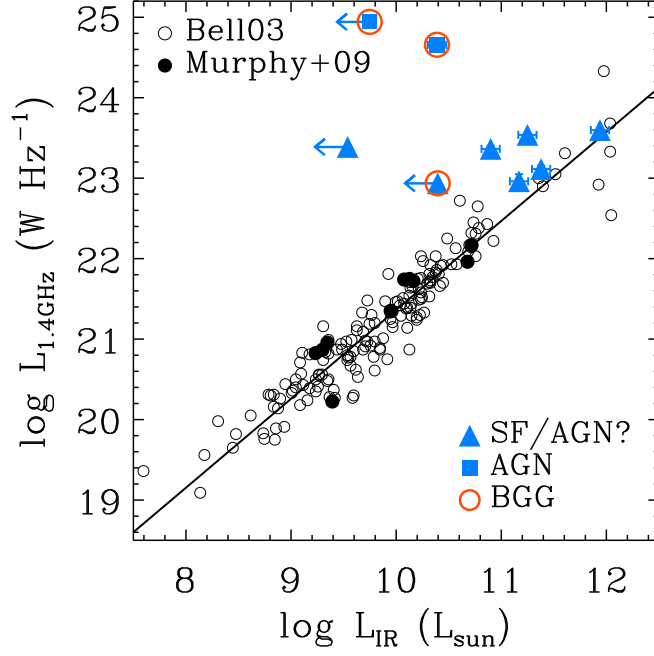


FIGURE 2. Comparison of the total infrared luminosity as measured by the $24\mu\text{m}$ flux to the radio luminosity at 1.4 GHz. Galaxies dominated by star formation lie on the solid line, as illustrated by data on local galaxies (open circles) [19] and Virgo members (solid circles) [20]. The supergroup galaxies are shown as solid triangles (star-forming/AGN) and solid squares (AGN); the radio-detected brightest group galaxies are circled.

Figure 1 (left panel) shows how the fraction of $24\mu\text{m}$ members in the supergroup steadily increases with decreasing local galaxy density as measured by distance to the 10^{th} nearest spectroscopically confirmed neighbor. The increasing fraction of emission-line members with decreasing Σ mirrors the trend of the $24\mu\text{m}$ members, and the absorption-line fraction changes accordingly. In contrast, the $24\mu\text{m}$ population in the cluster (right panel) shows a visibly weaker trend with local environment. The group galaxies have an infrared-density relation where at the lowest galaxy densities, the $24\mu\text{m}$ fraction in SG1120 is even higher than in the field ($\bar{z} = 0.35$). A complete analysis and discussion of the $24\mu\text{m}$ population as a function of environment is presented in Tran [18].

Because the $24\mu\text{m}$ emission can be due to ongoing star formation or AGN, we compare the group galaxies' total infrared luminosities to radio luminosities measured with the VLA in the A-array (resolution of $\sim 1.7''$). Nine of the group galaxies are detected at 1.4 GHz and we show their radio vs. total infrared luminosities in Fig. 2. Five of the radio-detected group galaxies have IR/radio ratios consistent with normal star formation. However, four members, including three of the four brightest group galaxies (BGG), have IR/radio ratios indicative of AGN. The 1.4 GHz map also reveals that one of the BGGs has extended radio jets (~ 100 kpc across).

To summarize, we find that SG1120 ($z = 0.37$), a protocluster made of four galaxy groups, has an excess of $24\mu\text{m}$ members compared to a massive cluster at $z = 0.33$. However, the fraction of early-type galaxies in SG1120 is already as high as in the cluster, *i.e.* the timescales needed to morphologically transform galaxies into early-type systems is decoupled from when their star formation is quenched. SG1120 also has nine radio sources of which at least $\sim 30\%$ are due to AGN rather than ongoing star formation. We are currently analyzing the radio observations in detail to better estimate, *e.g.* how much energy the AGN inject into the intragroup medium and whether the AGN are related to the excess of $24\mu\text{m}$ sources.

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